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MORPHOLOGY, STRUCTURE AND ACTIVE TECTONISM OF THE INSULAR MARGIN OFF NORTHWESTERN HISPANIOLA

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ABSTRACT

Long-range sidescan sonar, multichannel and single channel seismic reflection profiles and bathymetric surveys were carried out off northwestern Hispaniola (north of Haiti and the westernmost Dominican Republic. The morphology and structure of the insular slope define three distinct and abruptly bounded compartments. In the central compartment (Type I), the insular slope surface (the sea floor) is approximately planar, dipping about 4°, and internal structure consists of broad anticlines between thrust faults, with a gradational structural contact to undisturbed basin strata to the north. In the eastern and western compartments (Type II), the insular slope is convex and much steeper (9° to 16° for the lower slope) internal structure appears chaotic (presumably complexly folded and faulted), and the foot of the slope marks an abrupt structural front against undisturbed basin strata. The insular slope has formed as a tectonic accretionary wedge resulting from motion between the North American and Caribbean plates which has caused continuing crumpling of Hispaniola Basin sediments (dominantly turbidites) against the backstop formed by the island of Hispaniola. Although overall motion at the plate boundary is primarily transcurrent, the study region is a zone of transpression, and the structure of the insular slope has been dominated by compressional effects. We speculate that the difference in dip of the sea floor between compartments may result from variations in dip of the main decollement at the base of the tectonic accretionary wedge, and that the differences in internal structure may, in turn, result from the differences in sea-floor dip.

INTRODUCTION

The insular margin north of western Hispaniola (off Haiti and the western Dominican Republic) lies in the plate-boundary region between the North American and Caribbean plates. The dominant motion between these plates along the northern boundary of the Caribbean region is left-lateral transcurrent. However, apparently due to a slight convergence of plate trajectories and the presence of a restraining bend, the insular slope north of western Hispaniola is affected by compression, although probably not by subduction (Bracey and Vogt, 1970; Mann et al. 1984; Pindell and Barrett, 1988), and its structure is that of a tectonic accretionary wedge (Austin, 1983). This paper examines the morphological and structural variation in this region using sidescan-sonar imagery, seismic profiles, and echo-sounder bathymetry.

DATA

Long-range sidescan-sonar data were obtained during a U.S. Geological Survey cruise using the GLORIA system (Somers and others, 1978), which provided sea-floor images having a swath width of 40 km in the deep-water part of the Hispaniola Basin. Initial picture-element (pixel) size is about 50 m across-track by 150 m along-track; this is the effective resolution. The digital data were processed to present a 50- by 50-m pixel size (Chavez, 1986). Four multichannel seismic-reflection profiles were obtained by the University of Texas using a seismic source consisting of four 1500-in^3 airguns and a 48-trace streamer having 70-m group intervals. Data were

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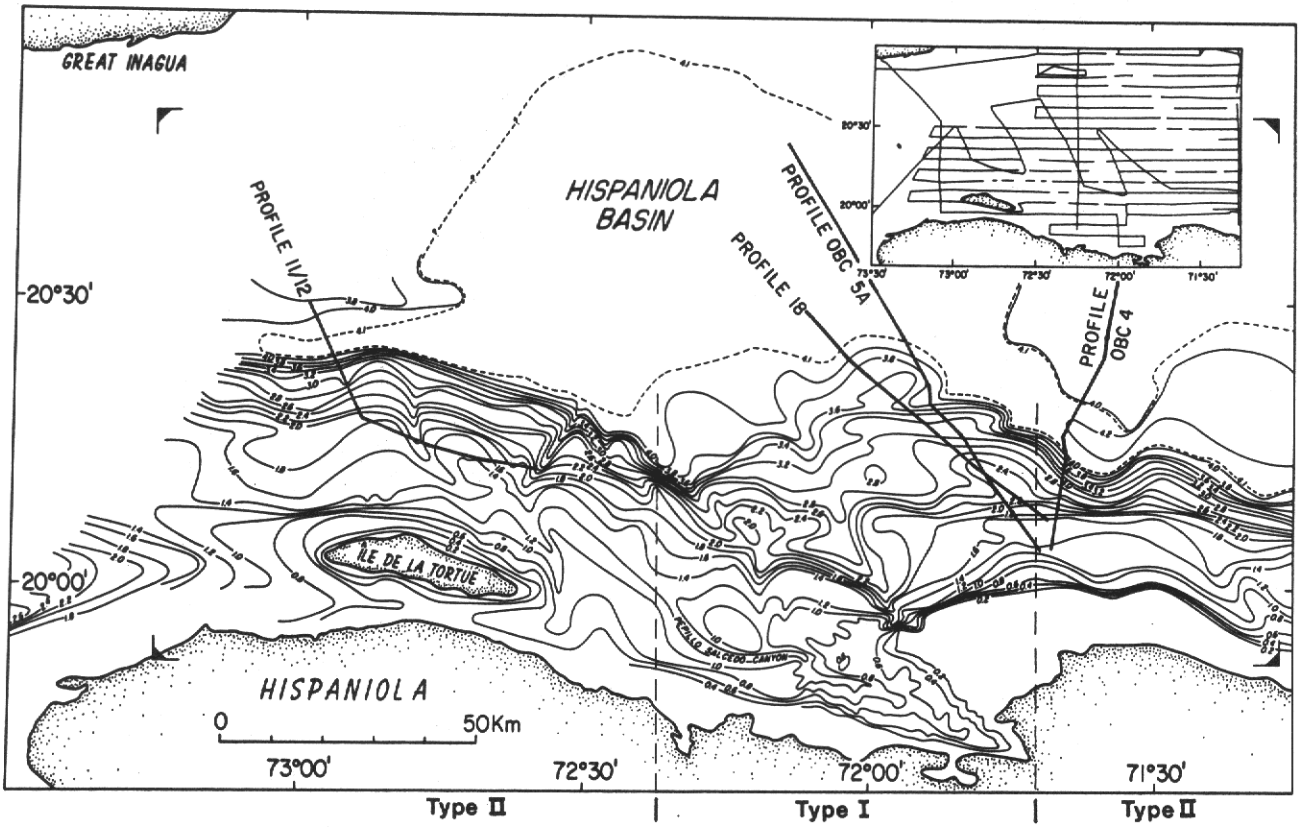

Figure 1. Contours of depth in kilometers of the continental margin off northwestern Hispaniola. Inset map shows data tracks. These were supplemented by a survey and contouring by N.T. Edgar in the Pepillo Salcedo Canyon area. The supplementary 4.1 km contour (dashed) indicates the approximate boundary of the flat-floored part of the Hispaniola Basin.

stacked 24-fold. Single-channel seismic profiles were collected along all GLORIA tracks using a 180-in^3 airgun. For purposes of structure mapping and creation of bathymetric sections across the margin, seismic profiles previously collected by Woods Hole Oceanographic Institution also were consulted (Uchupi, et al., 1971; Goreau, 1981). Digital bathymetric data were collected during Oregon State University and U.S. Geological Survey cruises (bathymetry coverage is shown in the inset map of Figure 1).

MORPHOLOGY OF THE INSULAR MARGIN

A bathymetric map of the study area (Fig. 1) discloses that the morphology of the insular slope comprises two distinctly different styles that occupy abruptly bounded compartments of the slope. A central compartment from about 71°42'W to 72°22'W (marked Type I in Fig. 1) extends farther north than the Type II areas to either side. Contours are more broadly spaced on the lower slope and generally are more random, defining irregular ridges. In the Type II areas to the east and west, lower-slope contours are more even and closely packed than in Type I, indicating a steepening of the slope toward the base. The differences between types are displayed in Figure 2 in a series of profiles plotted on north-south lines of projection from west (line A) to east (line I). Profiles in the Type I area (starred profiles E, F and G) show that the insular slope is planar or slightly concave, and has a dip angle of about 4°, whereas in the Type II area, (profiles A,B,C,D, H, and I) the slope is convex and has an angle near its base of 9° to 16°. The contact of the base of the slope and the Hispaniola Basin floor is gradational in Type I, but forms a very abrupt angle in Type II.

GLORIA sidescan-sonar imagery has been used to guide the contouring of Figure 1 and a portion of the GLORIA data is shown in Figure 3 to demonstrate the contrast between Type I and II areas at a boundary between compartments. The broad ridges and valleys of Type I contrast with the smaller scale roughness of Type II, and the generally greater breadth of the slope in Type I is apparent. The ridges in Type I are roughly parallel to the insular margin, but a break through them has created a submarine canyon that

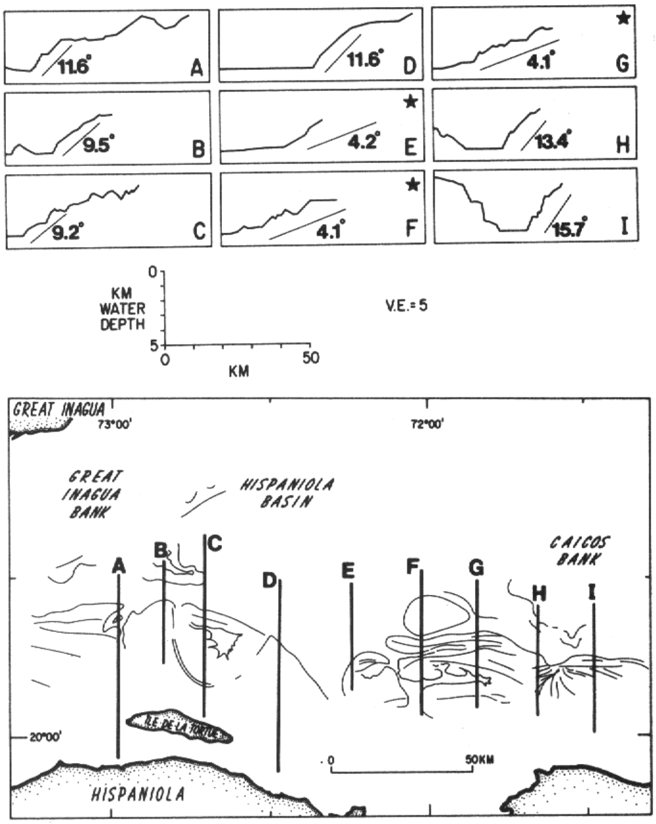

Figure 2 Bathymetric profiles of the insular margin off northwestern Hispaniola in the study area. The profiles are along north-south lines of projection from west (line A) to east (line I). Estimated average dip of the lower slope is indicated by a fine line and indication of angle in degrees in each profile. Starred profiles are in the Type I area; other profiles are in the western Type II area (profiles A-D), and eastern Type II area (H and I). Locations of lines of projection are shown in the map below the profiles. This map also indicates as light lines the principal sea-floor reflections observed in our GLORIA sidescan-sonar survey.

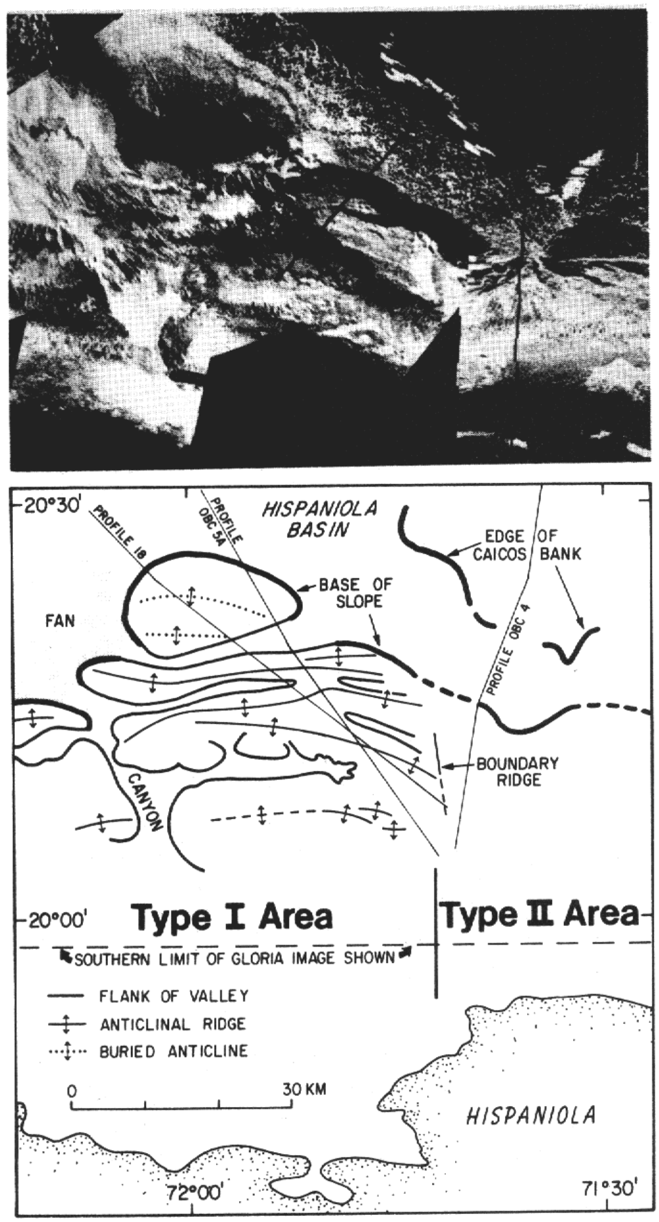

Figure 3. A portion of the GLORIA sidescan sonar mosaic and interpretation covering part of the central (Type I) area and eastern (Type II) area. The GLORIA image (top) covers the area above the dashed line in the interpretation (bottom). The limit of the deep (approximately 4100m), flat-floored, part of the Hispaniola Basin is indicated by a heavy line at the base of the Hispaniola insular slope or edge of Caicos Bank.

feeds turbidity flows to a fan at its mouth and to the floor of the Hispaniola Basin (see "canyon" and "fan" in Figure 3) (Bennetts and Pilkey, 1976; Ditty et al., 1977). The floor of the canyon and the fan are strongly reflective, probably because they are covered by a coarse lag deposit resulting from turbidity current flow.

STRUCTURE OF THE INSULAR MARGIN

Seismic-reflection profiles across the Type I area show that the broad ridges that are characteristic of this area are formed by anticlines (Figs. 4 and 5; locations of profiles shown in Figs. 1 and 3). Some buried anticlines that presumably have not yet grown upward enough to form ridges also were identified (note mapped anticlines shown in Figure 3). The amplitudes of the folds increase continuously toward the south from the flat, undisturbed strata of the

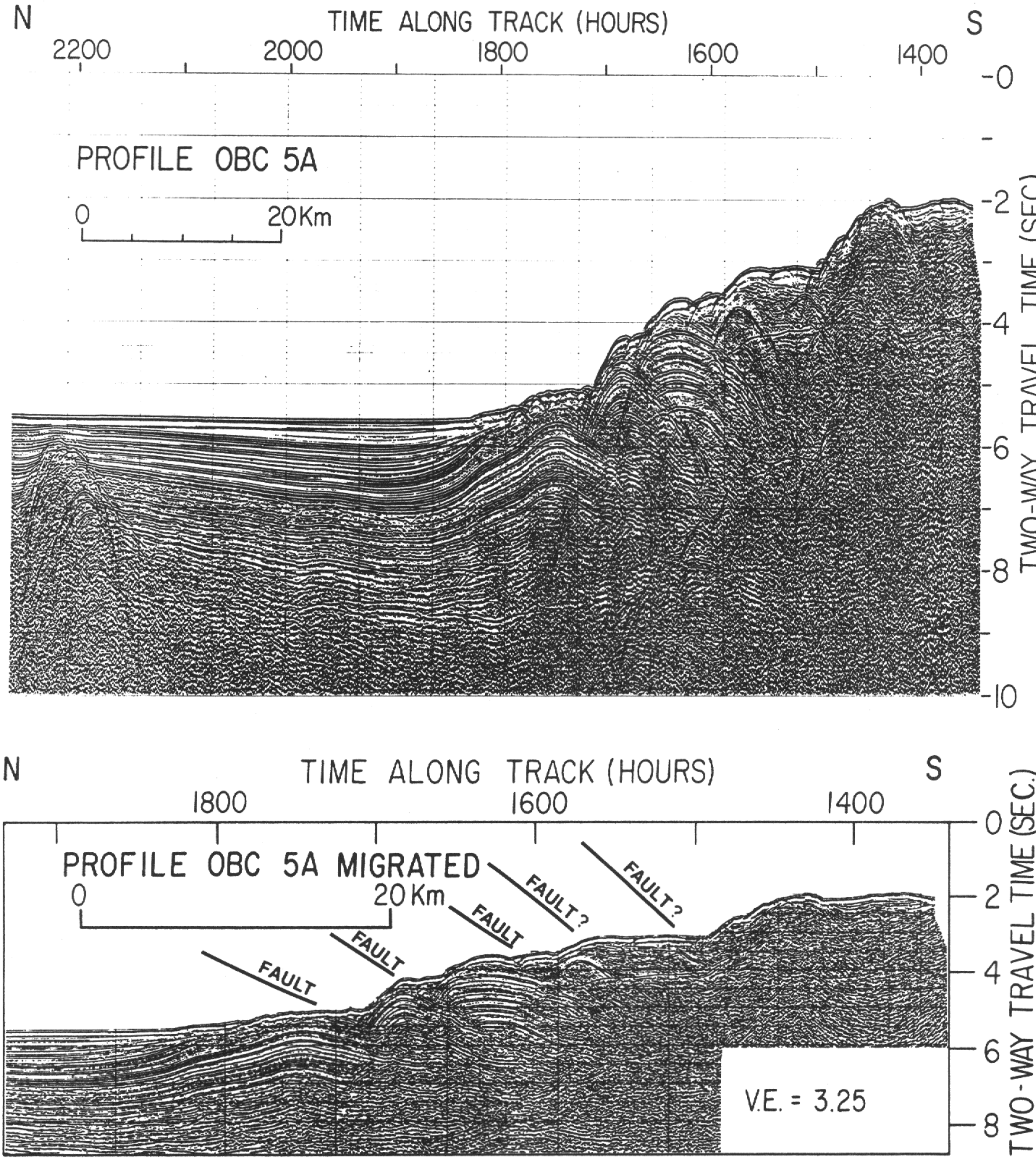

Figure 4. Multichannel seismic-reflection profile OBC 5A showing folds and thrust faults of the Type I area. Upper section received standard processing (Austin, 1983); vertical exaggeration is 8.4:1. Lower section is a migrated version of the central and southern part of the upper profile at lower vertical exaggeration; vertical exaggeration is 3.25:1. See Figures 1 and 3 for location.

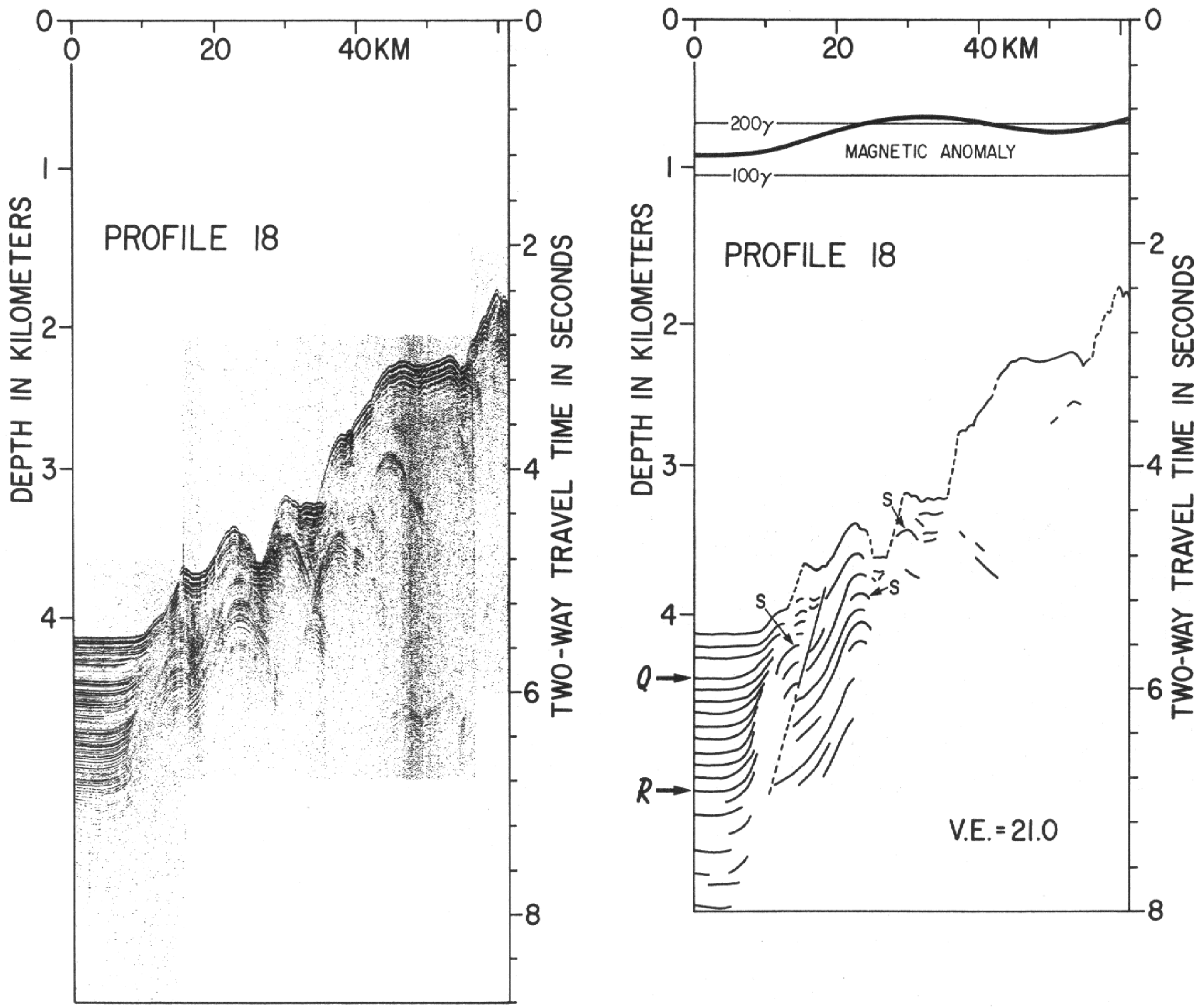

Figure 5. Single-channel seismic-reflection profile 18 and interpretation in Type I area. Vertical exaggeration is 21:1. See Figures 1 and 3 for location. A distinctive reflecting horizon (labeled S) appears to be recognizable at several locations. Its distribution suggests that it has been thrust up by the folding and faulting.

Hispaniola Basin, suggesting that folding has been progressive, occurring earliest at the south. Fold amplitudes also increase downward (Figs. 4 and 5), further indicating that folding has been continuous for some time and that the folds are syndepositional. The deeper-penetrating, multichannel profile shown in Figure 4, is interpreted to indicate that the anticlines are separated by thrust faults. The lack of correspondence of magnetic anomaly pattern to structure and the small amplitudes of the anomalies suggest that the basement beneath the insular slope is not involved in the folding (Fig. 5).

Seismic-reflection profiles in the Type II areas also show the smaller scale roughness of these insular slopes that was noted in GLORIA images, and the profiles display the greater steepness and convexity of this type in cross-section (Figs. 6 and 7). The abrupt angular contact of the slope to the basin floor is interpreted to be a structural front. Neither the large-source multichannel profiles nor the smaller-airgun, higher-resolution, single-channel profiles show significant subbottom structure in the Type II areas. Most subbottom reflections in the multichannel profile (Fig. 6) represent diffractions.

The boundaries between compartments are extremely abrupt and probably require structural

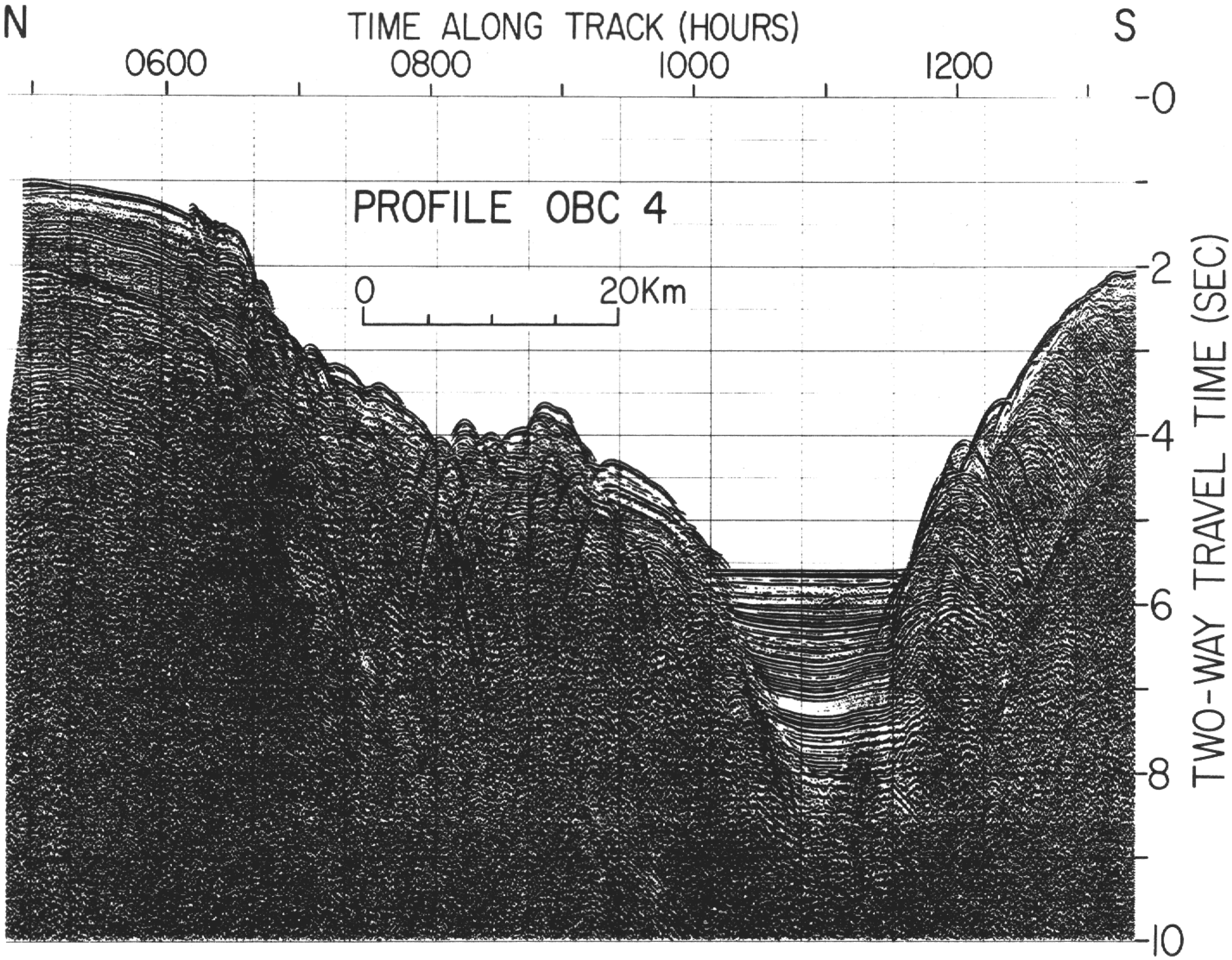

Figure 6. Multichannel seismic-reflection profile OBC 4 in eastern Type II area. Processing and vertical exaggeration are comparable to those of the upper profile of figure 4; vertical exaggeration is 8.9:1. The Hispaniola insular margin is on the right, showing a convex form and general lack of coherent internal structure. Caicos Bank is on the left, showing the typical collapse features of carbonate bank margins. See Figures 1 and 3 for location.

breaks that cross the insular margin. Evidence for such a break is present at least at the east side of the Type I area, where a north-trending ridge probably marks the structural feature that bounds the compartments. This ridge is apparent in the GLORIA image ("boundary ridge" in Figure 3) and is crossed by profile 18 at its southern end (Fig. 5).

MORPHOLOGY AND STRUCTURE OF THE INSULAR MARGIN: REVIEW AND IMPLICATIONS

We have observed very distinct differences in morphology and structure in well-defined compartments of the northwestern Hispaniola insular margin. These are summarized in Table 1 and sketched in the conceptual block diagram (Fig. 8).

The insular margin off northwestern Hispaniola clearly is a tectonic accretionary wedge. The sediments of the Hispaniola Basin are being compressed against the backstop of Hispaniola by motions of the North American and Caribbean plates. In the Type I area, the basin strata are being folded into broad anticlines, then the folds are truncated by thrust faults and shoved beneath a pile of earlier-formed folds that previously had been sliced off in their turn as the plates moved toward each other. The resulting Type I structure is well displayed in Figure 4. The anticlinal ridges that dominate Type

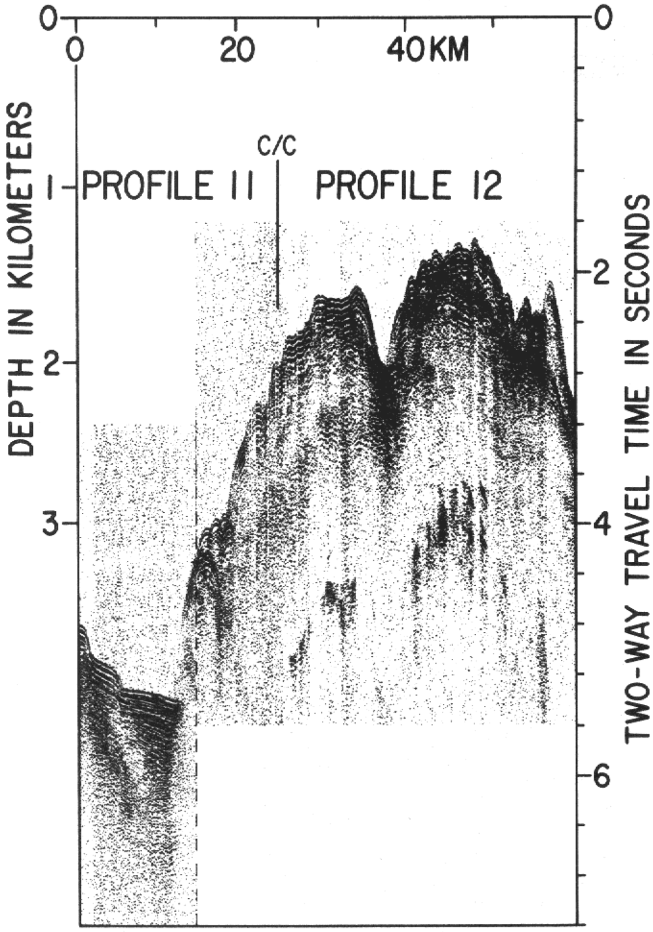

Figure 7. Single-channel seismic-reflection profiles 11/12 in western Type II area. C/C indicates course change. Vertical exaggeration is 20:1. See Figure 1 for location.

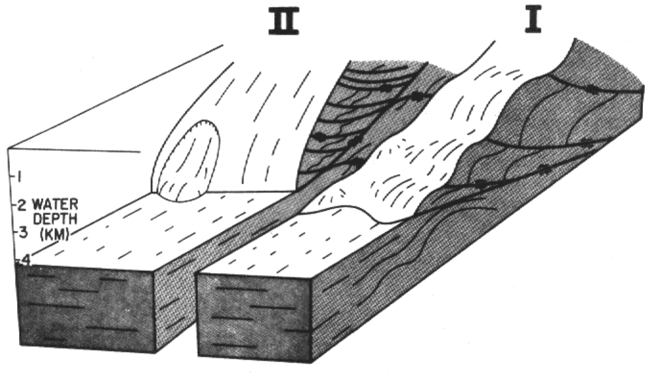

Figure 8. Conceptual block diagrams showing interpreted structure of the two morphological/structural types of the insular margin off northwestern Hispaniola.

COMPARISON OF INSULAR SLOPE TYPES, NORTHWESTERN HISPANIOLA

TYPE I	TYPE II
GENTLE SLOPE, ABOUT 4°	STEEP SLOPE, 9°-16°
INTERNAL STRUCTURE: THRUST FAULTS BETWEEN BROAD ANTICLINES	INTERNAL STRUCTURE: APPEARS CHAOTIC IN SEISMIC PROFILES
GRADATIONAL STRUCTURAL CONTACT TO BASIN STRATA	ABRUPT STRUCTURAL FRONT AGAINST BASIN
PLANAR TO CONCAVE	CONVEX

Table 1.

I morphology result in the formation of a structurally-controlled submarine canyon system. The internal structure of Type II insular slopes is not displayed by either of the seismic-reflection systems that we used. Thus we refer to this structure as chaotic; it consists, perhaps, of tight folds and complex faults. However, in such a small area, both Types I and II insular slopes and their internal structures must have been formed by the same plate interactions.

Although this insular margin is located near a plate boundary that is dominantly transcurrent, no structural features typical of strike-slip faulting, such as evidence of linear, vertical faults, or flower structures, have been observed in seismic profiles. Rather all structure in the insular slope seems to be related to compression. The actual strike-slip motion at the plate boundary may be marked by the trend of seismicity along the coastline; very few earthquakes occur on the insular slope (Sykes et al., 1982; National Geophysical Data Center, Boulder, CO, Earthquake Data Base). In a region of transpression, broad zones of pure compression flanking a narrow zone of pure transcurrent motion may be the common situation, in any case (Mount and Suppe, 1987).

SPECULATION ON CAUSES OF STRUCTURAL AND MORPHOLOGICAL VARIATION

Two principal questions arise: (1.) Why are the slope angles so different between types? (2.) Why are the internal structures apparently so different?

Differences in slope angle

Tectonic accretionary wedges are common features of collisional plate interactions. As noted above, even in oblique collision, strains tend to be organized into a narrow zone of pure transcurrent motion at the plate boundary, with broader, flanking zones where shortening is normal to the plate boundary, and accretionary wedges can form. Such a wedge is comparable to the pile of snow in front of a constantly moving snowplow, in which the pile will maintain its shape in front of the moving blade in a dynamic way, as long as all factors remain the same. At the front of a tectonic accretionary wedge, the angle between the sediment surface and the decollement is referred to as the taper. The critical taper is the constant angle that will be maintained at steady state when the basal decollement and the sediments of the wedge are everywhere at the point of failure (Davis et al., 1983; Dahlen et al., 1984). Critical taper depends on the internal strength of the wedge balanced against four forces, the compressive push of a backstop (of Hispaniola in this case), the basal frictional resistance (at the decollement), the gravitational body force (the tendency for any slope to spread out flat under the influence of gravity), and the pressure of overlying water. Hence, at the front of a tectonic accretionary wedge such as that north of Hispaniola, abrupt changes in sea-floor dip could result from abrupt changes in any of the four forces or in the internal strength of the wedge, any of which would cause changes in the critical taper. Alternatively, such a change in sea-floor dip could result from a change in the dip of the decollement while critical taper remained constant.

Which of these factors seems likely to be responsible for the major variations along the northwestern Hispaniola insular slope? Water depth at the top and bottom of the wedge does not change along the margin, so pressure does not vary, and it is difficult to visualize how the gravitational body force could change abruptly . The Hispaniola backstop apparently is rigid and continuous along this segment of the plate boundary, as structures, including faults, trend parallel to the insular margin within the island, affording no opportunity for the segmentation of the backstop (e.g. Bowin, 1975). Therefore, distinct variations in compressive push seem unlikely. Basal frictional resistance can be affected by fluid on the decollement, but it is not clear how this would be compartmentalized. Therefore, the four forces do not seem to be good candidates for abrupt change, and we are left with a need to vary the internal strength of the wedge or the dip of the decollement. Internal strength might change if material entering the accretionary wedge at two points were radically different. If, for example, a component of the carbonate Bahama Banks had been dragged into the wedge, such a block would be stronger than the Hispaniola Basin turbidite sediments and therefore would cause a large increase in critical taper and in the stable angle for the insular slope. Thus a Type II area might be formed. Although this could have happened, we have no evidence for it in the seismic profiles and, therefore, do not propose such a scenario.

Variations in any of the factors considered in the previous paragraph would have modified the dip of the slope by changing the angle of the critical taper, but a change by a very large value would be required to account for the observed insular slope morphology -- a change of more than 11° at some locations on the basis of the angles indicated in Figure 2. Such a large change seems unlikely, as most critical tapers reported are within a fairly small range (e.g., in 10 of 12 cases reported by Davis et al., 1983, critical tapers were in the range of 7° to 10° and none exceeded 10°). In this study area, north of Hispaniola, where apparently similar basin deposits are being crumpled into a small wedge, which has apparently similar conditions along it, we expect that the critical taper would not vary radically.

If the critical taper does not vary extremely, as seems likely, then the decollement must dip at varied angles so that the top of the tectonic accretionary wedge (the insular slope) can vary in dip as it does. The structure of the margin in the Type I area, with a 4° surface slope, is considered to be that sketched in the idealized block diagram (Fig. 8, right block), in which the decollement dips toward the south. However, Type II slopes range from 9° to 16° (Fig. 2). If the critical angles in both the Type I and Type II areas are similar to those indicated in the literature as noted above (less than 10°), this would require that, in many Type II cases, the decollement must rise toward the south (dip northward toward the toe of the wedge). The space beneath such a southward-rising decollement would have to be filled by some structure such as a duplex. The proposed situation is sketched in the left block of Figure 8. Although our seismic profiles do not display this duplex (and probably no profiles could, in an area with such a complex topography, structure, and velocity field), it seems to be the most logical solution to the structural problem. Presence of a similar duplex beneath the accretionary wedge northwest of the Nankai Trough off Japan has been interpreted by Leggett et al. (1985).

Differences in internal structures

Whereas the Type I internal structure is characterized by broad folds separated by major thrust faults, the Type II appears to be chaotic, presumably consisting of tight folds and intensive, complex faulting, as sketched in Figure 8. The difference in structure may result directly from the differences in slope angles because increase in strength in sediments is strongly affected by overburden loading. On moving landward across a steep Type II slope, overburden will thicken much faster above a horizontal plane than on crossing a flatter Type I. For a unit amount of thickening, one would have to move 3.6 times farther across a 4° Type I slope than across a 14° Type II. In a Type I slope, the broader zone of weaker sediments, which is perhaps more appropriate for folding, may account, in part, for the broader wavelength of folds. The cohesive strengthening of sediments in the Type II situation is demonstrated by the convex curve of the slope profile, which actually results from a decrease in the critical taper resulting from the increase in strength on proceeding into the wedge, as demonstrated by Zhao et al. (1986).

SUMMARY

The insular slope north of western Hispaniola is a tectonic accretionary wedge, formed as a result of compressional components of transpression between the North American and Caribbean plates. Two very different morphological/structural types exist in distinct, adjacent compartments along the insular slope. In the central part of the study area, the Type I slope is planar, has a dip of about 4°, and its structure consists of broad anticlines separated by thrust faults. To the east and west of the central compartment, the Type II slope is convex (indicating a progressive landward increase in cohesive strength), has a dip of 9° to 16°, and has an internal structure that, in seismic profiles, appears chaotic (probably formed of short-wavelength folds and abundant, small faults). The compartment boundaries are abrupt, a condition that probably requires faults that cross the insular margin; evidence for one such structure is noted in sidescan sonar. We suggest that the difference in slope between the two types may result from differences in dip of the decollement beneath the tectonic accretionary wedge, because very large changes in the critical angle at the front of the wedge are unlikely. If this is correct and if the critical angle is comparable to others discussed in the literature (less than 10°), then the decollement would be expected to rise toward the south (dip toward the toe of the wedge) in some Type II areas. Such a structural model would require a complicating structure, such as a duplex, beneath the decollement in order to fill the space. We infer that the difference in structure within the wedge between Types I and II may depend on the variations in slope steepness, such that flatter slopes allow a broader zone in which sediments are weaker and therefore more easily folded.

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